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INSTRUMENTS AND METHODS

ELECTROCHAUDE: A SELF-FLUSHING HOT-WATER DRILLING APPARATUS FOR GLACIERS WITH DEBRIS

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ABSTRACT. In order to avoid problems stemming from the accumulation of rock fragments at the bottom of the hole during conventional thermal drilling in ice, a new type of probe has been developed. In this system, the water is warmed electrically inside the probe itself and propelled by a micro-pump. In this way, the hot water sprayed towards the ice scatters the insulating layer of debris and drilling continues normally, as shown by tests on several glaciers over the past 4 years.

INTRODUCTION

Ever since scientists first took an active interest in alpine glaciers, they have been overcome by an irresistible need to drill into them, penetrating beyond what they see as superficial in order to: measure their thickness; drive in stakes; pepper them with all kinds of transducers; and extract ice cores.

The researchers of the Laboratoire de Glaciologie et Géophysique have not been an exception to the rule and, in order to satisfy their ever-growing enthusiasm, the technical staff has had to develop various types of drill (Gillet, 1975). Considering the cost of helicopter transport, and other practical concerns related to field operations in rugged alpine areas, we have tried to minimize the weight and bulk of this equipment.

Although the steam drill remains unbeatable for the first 15 m of drilling, it very quickly loses its advantage at greater depths because of heat losses along the hose, and head losses due to the increasing height of the water in the hole. It is therefore mainly used for planting standard stakes down to depths of 10 or 12 m. For deeper drilling, other techniques using hot water are available, but they need more powerful and much more bulky equipment which cannot easily be moved on a glacier. For these reasons, work which started in 1971 led to the development of an electrical thermal drill with a silver head which was successfully used on various glaciers where the ice contains few rock fragments. In 1979, when we tried to implant stainless steel wires in glacier d'Argentière in order to study deformation by inclinometry, this type of device was unable to drill deeper than 100 m due to the excessive accumulation of gravel or sand at the bottom of the hole, and thus insulating the head from the ice. At the same time, the ablation-area study programme called for the installation of graduated wires in the tongue of the glacier, where the ice is often dirty.

We therefore had to develop another type of equipment capable of drilling in ice with scattered rock fragments, while still preserving the acquired advantages including lightness, compactness, and performance.

A submersible pump developed for another project (Gillet and others, 1984) was modified for installation in a small-diameter tube with the aim of providing a sufficient flow of water to clean the bottom of the hole. All that remained necessary to complete the design was to heat water filling the hole to melt the ice.

DESCRIPTION (Fig. 1)

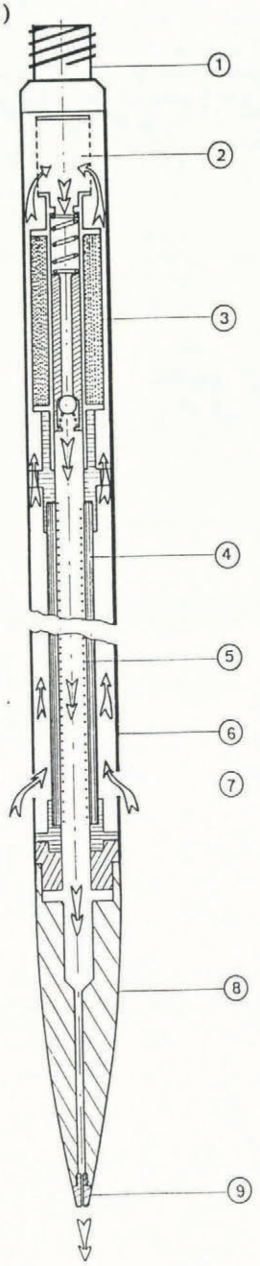

Fig. 1. Schematic diagram of the Electrochaude probe. (1) Connector; (2) Filter; (3) Electromagnetic pump; (4) Ceramic tube; (5) Heating wire; (6) Stainless steel tube (diameter = 28 mm); (7) Water inlet; (8) Nozzle; (9) Tip.

The drill comes in the form of a stainless steel tube 28 mm in diameter and 1.5 m long.

The upper part consists of an under-water electrical connection which electrically and mechanically joins the drill to the cable.

Below, the drill houses a filter and an electromagnetic pump (Fig. 2). Its coil is supplied by an alternating current and a diode in series acts as a half-wave rectifier. A piston forming a magnetic core moves alternately under the force of magnetic attraction and a pumping spring, forcing the water out of the priming cage at the frequency of the a.c. power supply.

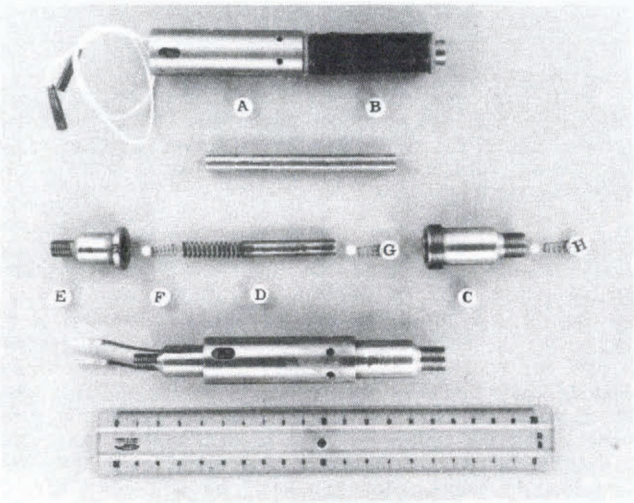

Fig. 2. Electromagnetic pump. A. Magnetic circuit; B. Coil; C. Priming cage; D. Piston forming magnetic core; E. Suction cage; F. Bottom valve; G. Priming valve; H. Delivery valve.

All the metallic parts are made of stainless steel in order to minimize corrosion.

There is also a refractory ceramic tube, 12 mm × 8 mm in diameter and 1 m long (Electroquartz SL 60 ZA), containing a Ni–Cr spiral heating wire (diameter 0.7 mm, 3.4 Ω/m) capable of dissipating 1600 W or more without being subject to damage if, for any reason, it should no longer be immersed.

At the bottom of the probe, a brass nozzle has a calibrated hole.

OPERATION

The water, drawn in 0.20 m above the nozzle through openings in the outer tube moves up along the ceramic tube, recovering any heat lost by the tube and the pump. With part of the solid impurities already removed from the water by settling, the filter takes out the remaining fines. The probe recovers only a portion of the debris at the bottom of the hole. The amount depends on the debris concentration in the ice, but it does not exceed 1 cm^3 after 100 m of drilling. This debris settles in the space below the water-inlet holes and can be removed at the end of drilling. Pumped into the central tube, the water is warmed by the heating element and exits as a steady jet, powerful enough to lift up any sand which could be lying at the bottom of the hole. Having transferred part of its heat to melt the ice, the water is drawn back into the drill.

The cable is hand-held during drilling so that the probe is suspended just above the bottom, and this is done to a depth of 150 m. (For deeper holes, it is necessary to use a winch and to control suspension.)

On the surface, an adjustable transformer (including a voltmeter and an ammeter) is used to increase the voltage to reduce the line losses. Power is supplied by a 3.2 kVA generator, but it can be also supplied by a 2 kVA generator when the altitude is sufficiently low or when the equipment has to be back-packed (glacier Bossons).

TECHNICAL CONSIDERATIONS

Nozzle

In the first version of the probe, the nozzle had a short parabolic shape and the water flow was adjusted by a needle valve. The mean drilling rate was 8.5 m/h.

In the new version, the nozzle has a long, smooth parabolic taper (Taylor, 1984). The hole diameter was determined by using several tips each drilled at a different size. Figure 3 shows the importance of the hole diameter in dirty ice. At the Mer de Glace, the maximum drilling rate (14 m/h) was obtained with a 1.2 mm hole, in spite of a low water-flow rate. This can be explained by the scattering effect due to the high pressure (Fig. 4). The water-flow temperature is about 30° to 40°C.

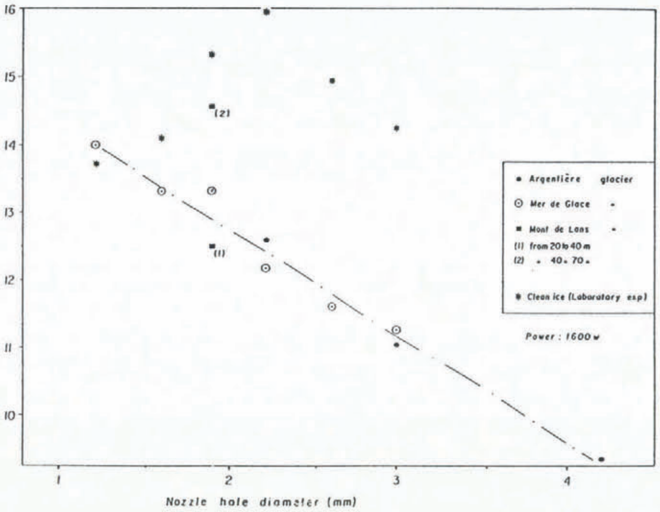

Fig. 3. Drilling rate (obtained from different glaciers) versus nozzle-hole diameter. In glacier Mont de Lans, the deep ice seems to be cleaner than the upper ice.

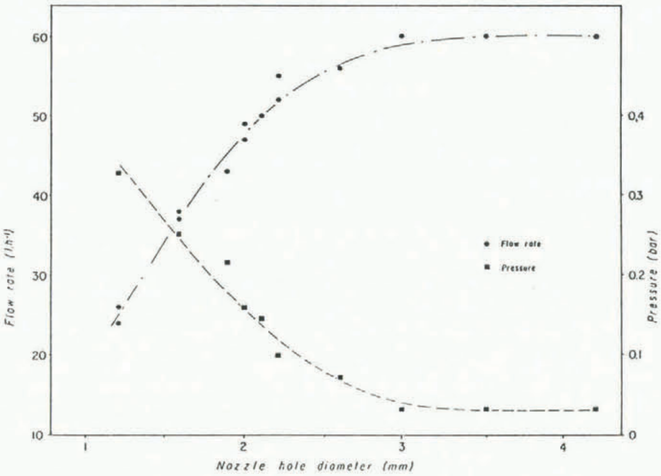

Fig. 4. Outlet pressure and flow rate of the pump versus nozzle-hole diameter.

Pump

The electrical supply for both the pump and the heating was initially divided. It ensured that the pump coil was supplied with 240 V. We encountered some problems due to power shortages. The electrical power supply is arranged in series so that the potential difference at the ends of the coil is low. It is also necessary to use another diode in order to get the two waves of current in the heating element (Fig. 5).

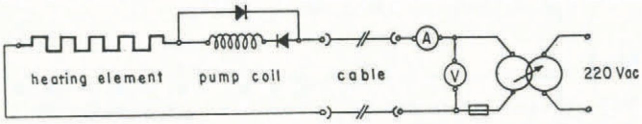

Fig. 5. Electrical diagram.

Absence of water

The only disadvantage of this system is its inability to work without water. However, this can be remedied by using a solid-nozzle probe which receives its thermal energy from a heating cartridge. In spite of its low rate of penetration, this allows a hole to be started at the surface and, if the hole empties during drilling, it is possible to continue the operation until water is again present.

Hole quality

As for all kinds of drill, both the verticality and the regularity of the hole depend largely on the care of the driller to keep the drill properly suspended. This is more important with a hot-water drill because the stream of water melts the ice directly beneath the nozzle and the probe follows this hole. It is therefore less easy to straighten the drill hole when necessary than with a solid-nose thermal drill. We have not used any form of calipers in the holes drilled so far, but we have had a good idea of their regularity when we introduced equipment (transducers, stakes, etc.) into the bore hole without trouble, making a smooth passage down the bore hole. We have no direct inclinometry data to check the verticality of the bore hole.

Drill efficiency

Theoretically, the maximum drilling rate (V) is related to the power supply (P) and the cross-section of the drill (S) by the equation:

$$P = SVL\rho$$

where L is latent heat of ice melting, ρ is ice density, then

$$V = \frac{P}{SL\rho};$$

if V is in m/h, P in W, and S in m^2, we can write (Gillet, 1975)

$$V = 1.17 \times 10^{-5}\frac{P}{S}. \qquad (1)$$

The ratio of the true drilling rate to the theoretical one gives the "effective rate" of the drill. For a drilling rate of 14 m/h and a power consumption of 1600 W, the effective rate of the drill is 50%. It also represents the ratio between the cross-sections of the drill and the hole. We can then determine the mean diameter of the bore hole:

$$(28^2)/(d^2) = 0.50,$$

$$d = (28^2/0.5)^{\frac{1}{2}} = 39 \text{ mm}.$$

Considering Equation (1), the drill speed could be improved by increasing the power supply, but this requires a more powerful and heavier generator. In addition, the cross-section of the drill could be reduced but this would make it much more difficult to package the internal elements and have easy access to them if repairs are necessary.

Improvements

In order to avoid overheating, in future we will equip the drill with a bimetallic thermostat which switches the power supply in case of a sudden water loss in the bore hole.

FIELD EXPERIENCE

Temperate glaciers

With more than 1200 m of holes drilled in the Blanc, Bossons, Argentière, Mer de Glace, and Mont de Lans glaciers, the drill has proved its effectiveness. The holes were started with either a steam drill or a solid-nozzle thermal drill.

Moderately cold glaciers

The drill was used on the Austfonna ice cap, Nordaustlandet, Svalbard, in May 1986. A tank was fixed to the top of the probe to inject antifreeze into the melt water (the ice temperature reached −10°C). We had planned to use ethanol but we only had ethylene glycol which created many problems due to its high viscosity at these low temperatures. In spite of these problems and the time spent filling the tank every 4 m of drilling, we were able to drill a 140 m deep hole and three 40 m deep holes for temperature measurements. In future, we will use a special cable that includes a hose for injecting ethanol continuously from the surface.

EQUIPMENT WEIGHT

Generator 2 kVA	35 kg	3.2 kVA	75 kg
Cable: 150 m	10 kg	250 m + winch	35 kg
Drill + spare parts	10 kg		
Transformer	10 kg		
Jerrycan of petrol (10–14 h of drilling)	20 kg		

CONCLUSION

It appears that we have attained our initial goal: the development of a small-diameter drill, easily transported, and capable of drilling through glacier ice in spite of fine rock debris, which is bound to accumulate at the bottom of the hole.

ACKNOWLEDGEMENTS

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